## Lecture 20: Interconnects

- **Announcements**:
- Lab 1 Report will be due Friday, April 23
  - Instructions for the report will online on the EE143 Lab link
  - You can (and should) start on it now!
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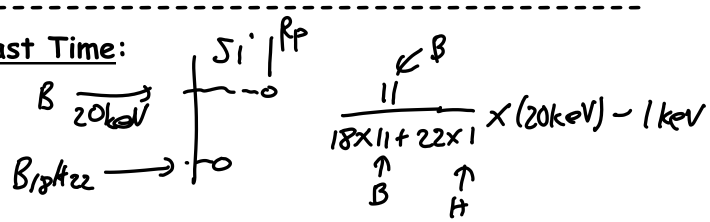
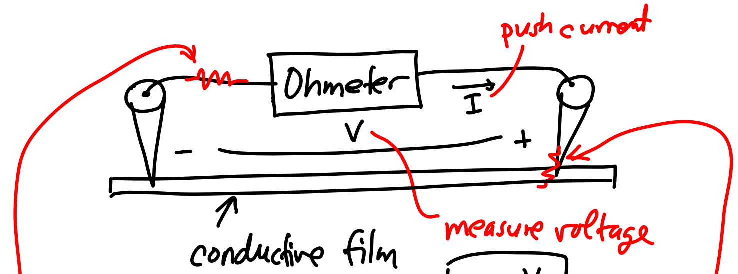
- **Lecture Topics**:
  - Advanced Diffusion
    - Effect of E-Field on Diffusion
    - Concentration-Dependent Diffusion
  - Interconnects & Contacts
    - Planar Process Compatible Metals
    - Ohmic vs. Diode Contacts
    - Sintering
    - Measuring Contact Resistance
    - Electromigration
    - Space-Saving Contact Strategies
    - Silicidation
    - Lift-Off
    - Multilevel Metallization
      - Damascene Process
  - Metal MEMS Surface-Micromachining
- ------------------------------------
- **Last Time**:



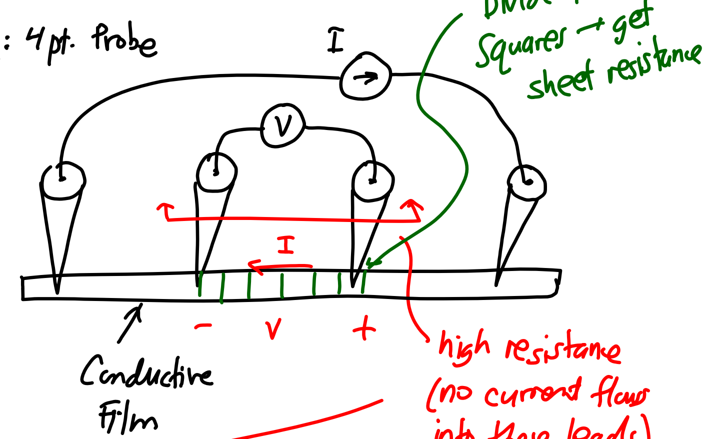

- How does one measure the resistance from one point to another accurately?




$R = \frac{V}{I}$

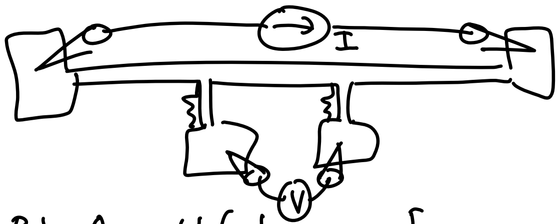
Problem: What about:
(1) the resistance in the leads?
(2) the contact resistance (which can be high)?
↳ How can you tell your film's resistance vs. these?

Soln: 4pt. probe

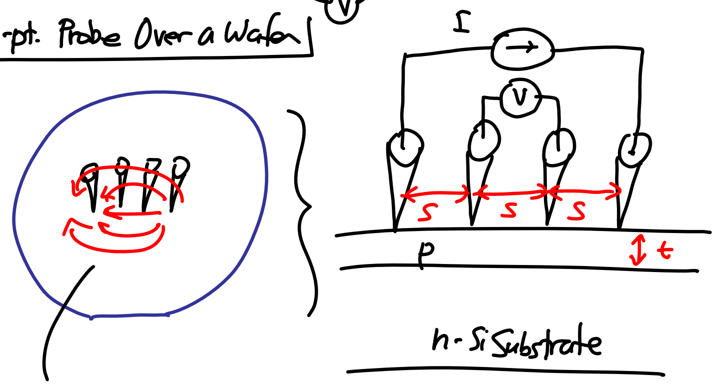



$R = \frac{V}{I}$

↳ Get the R between the two inner probes, and only the inner probes (even contact R nulled out)




4-pt. Probe Over a Wafer




Current now distributed.

⇒ resistivity expression:

$$\rho = 2\pi s\left(\frac{V}{I}\right)\ \Omega\cdot m \quad \text{for } t \gg s$$

$$\rho = \left(\frac{\pi t}{\ln 2}\right)\cdot\left(\frac{V}{I}\right)\ \Omega\cdot m \quad \text{for } t \ll s$$

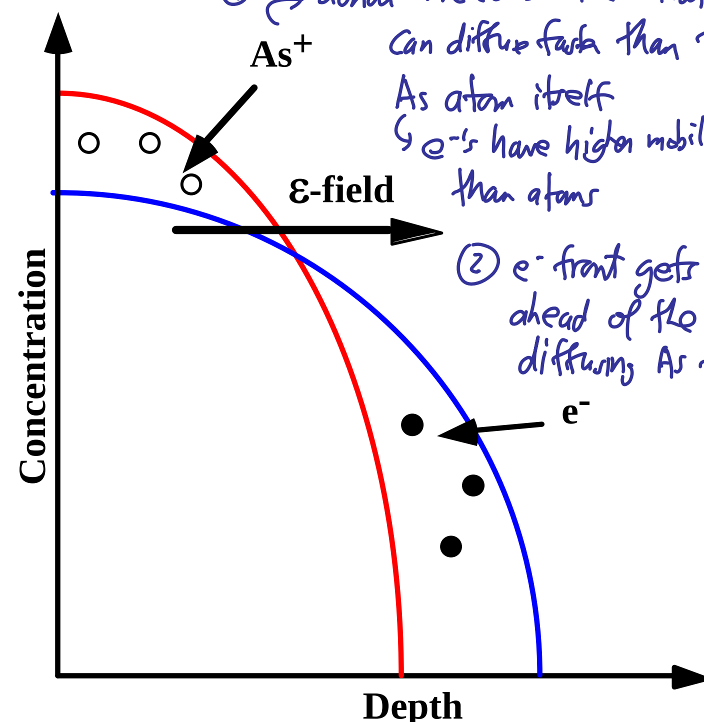
→ This is the more relevant case:

$$R_s = \frac{\rho}{t} = \left(\frac{\pi}{\ln 2}\right)\cdot\left(\frac{V}{I}\right)\ \Omega/\square = 4.53\,\frac{V}{I}\ \Omega/\square \quad (t \ll s)$$

## 2nd Order Diffusion Effects

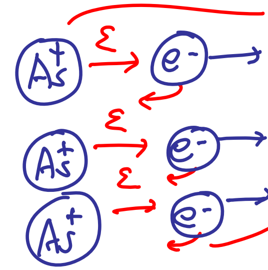
### Effect of Electric Field on Diffusion

① ↳ donor → releases an e⁻ that can diffuse faster than the As atom itself
↳ e⁻'s have higher mobility than atoms




② e⁻ front gets ahead of the diffusing As front

Pictorially: (for n-type)



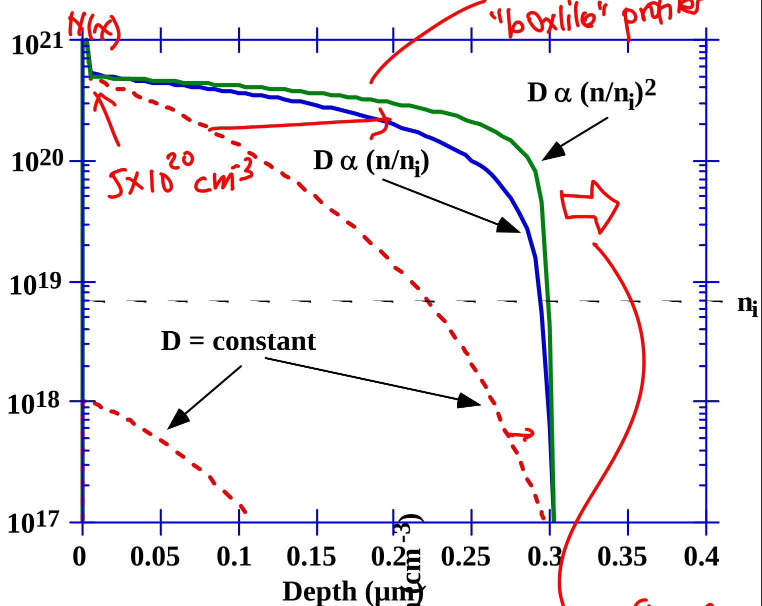

ions pulled to the right faster than normal due to the ε-field

③ ε-field also slows the e⁻'s down
↳ achieve equilibrium

(4) Result: D is larger than expected!

Concentration-Dependent Diffusion

After diffusion, get "boxlike" profiles



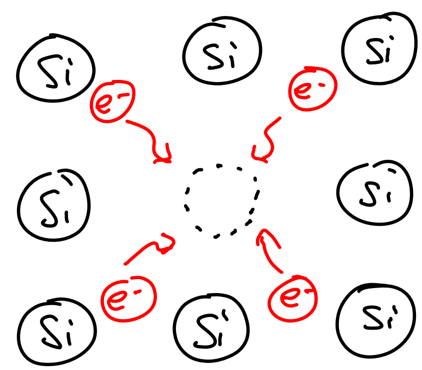

Larger flux for high N(x) regions than for low N(x)!

@ high doping conc., the diffusivity appears to increase!

- Why is this happening?
  - Since diffusion involves both the dopant and a vacancy that it can move into, it can be modeled as the movement of a dopant-vacancy pair
  - The rate of diffusion depends upon the charge state of the vacancy

| Possible Diffusion Species | $I\cdot V^0$ | $I\cdot V^+$ | $I\cdot V^-$ | $I\cdot V^{2-}$ | $I\cdot V^{3-}$ |
|---|---|---|---|---|---|
| Diffusion Const. | $D^0$ | $D^+$ | $D^-$ | $D^{2-}$ | $D^{3-}$ |

where $I\cdot V^x$ ← charge state of the vacancy; I = impurity atom; V = vacancy




(1) When doping level is high → lots of e-'s.

(2) Vacancies can soak up e-'s ∴ gotta charge

(3) Get "charged vacancy" → get more of them when doping level is high!

The net diffusion is the sum of the various components:

↳ D can be well described by:

$$D_A^{eff}(n\text{-type}) = D^0 + D^-\left(\frac{n}{n_i}\right) + D^=\left(\frac{n}{n_i}\right)^2$$

$n \rightarrow N_D$

$n_i$: intrinsic conc.

$D^0$: diffusivity of a dopant-neutral point-defect pair

$D^-$, $D^=$: diffusivities of charged point-defect pairs